Journal of Special Topics

A1_4 Thermal Properties of an Igloo

S. Jinks, R. Hopton, T. Glossop

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

February 23, 2011

Abstract

This paper investigates the thermal properties of an igloo. Assuming a steady state system of a single human body radiating heat inside an igloo, this paper predicts that a temperature difference between inside and outside of the igloo of $\Delta T \approx 49$K could be maintained. Limitations to this model are discussed.

Introduction

Igloos are domed houses made of blocks of ice "glued" together with snow, often associated with the Inuit people of the Canadian Arctic [1]. Igloos are known to effectively keep humans warm in very cold environments, but how?

Loosely packed snow has air spaces between snow crystals, which cause it to act as an insulator [2]. The wall and floor of an igloo comprised of, or covered in, snow could, therefore, theoretically keep a human's body heat inside the structure.

Figure (1) shows a simple model of an igloo with a human inside:

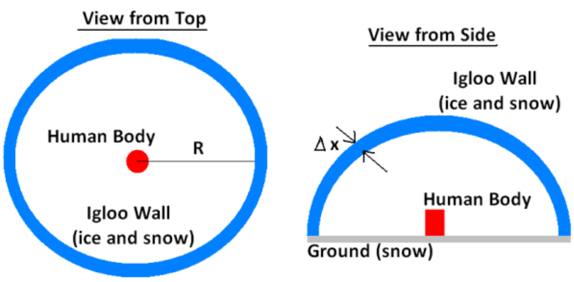

Figure (1): Igloo Model Schematic.

Heat transfer occurs via conduction, convection and radiation. The air surrounding the human body would increase in temperature due to conduction and radiation. As a result, the density of this warmer air decreases and, due to buoyancy, is pushed up towards the top of the igloo. Cool air next to the igloo wall/roof would flow downwards, as it is denser than the rising warmer air.

Thus, a convective circulation flow would be created inside the igloo, so the temperature inside is not constant.

Analysis

The rate of flow of energy (thermal current) [3] through the igloo walls is given by:

$$\frac{dQ}{dt} = -\kappa A_I \frac{dT}{dx} = -\kappa A_I \frac{(T_i - T_e)}{\Delta x}, \qquad (1)$$

where κ is the thermal conductivity of the packed snow ($\kappa \approx 0.25\text{Js}^{-1}\text{m}^{-1}\text{K}^{-1}$ at sub-zero temperatures [4]). A_I is the internal surface area of the igloo equivalent to $2\pi R^2$ (simply taking the curved walls of the igloo as the area through which heat is lost, assuming no heat loss to the ground). Δx is the thickness of the igloo wall and (T_i–T_e) is the difference in temperature between the interior and exterior of the igloo. As explained in the introduction, the temperature of the interior is not constant, due to convection, so T_i is the average temperature of the air inside the igloo.

We can use the Stefan–Boltzmann law for blackbody radiation [3] to determine roughly the amount of heat emitted by the human body inside the igloo in a given time:

$$P_h = \frac{Q_h}{t} = \varepsilon_h \sigma A_h T_h{}^4, \qquad (2)$$

where P_h = the power radiated by the human at temperature T_h (assuming our human subject is naked, the skin temperature T_h = 306.15K (33°C), which is the "comfortable" skin temperature for a human [5]). ε_h = the emissivity of the radiating human (human skin is almost a perfect emitter, or blackbody, with an emissivity of $\varepsilon_h \approx 0.98$ [6]). A_h = surface area of the radiating human (A_h = 2.12m^2 for an average human of height 1.8m and mass 90 kg [7]). σ = Stefan's constant = 5.6703x10^{-8} Wm^{-2}K^{-4}.

Assuming that the system has had time to reach a steady state, in which the heat produced by the human can be equated with the heat conducted by the igloo to the outside,

$$-\kappa A_I \frac{(T_i - T_e)}{\Delta x} = \varepsilon_h \sigma\, A_h {T_h}^4. \qquad (3)$$

Solving this expression for ($T_e - T_i$) gives:

$$\Delta T = (T_e - T_i) = \frac{\Delta x\, \varepsilon_h \sigma\, A_h {T_h}^4}{\kappa\, 2\pi R^2}. \qquad (4)$$

Given the values stated above, along with arbitrary values of R = 2.0m and Δx = 0.3m: $\Delta T \approx$ 49K. In a region of Greenland, where igloos exist, the night temperatures can get as low as 230.15K (-43˚C) [8]. So, even on the coldest nights, this theory predicts that the inside of the igloo could still be as warm as 279.15K (6˚C) with just one adult human inside.

Discussion

By changing the values for the thickness of the igloo, Δx, and its radius, R, the difference in temperature obtained might be unrealistically high. This suggests that our model requires additional refinement.

Ideally, to determine how warm the air is by the interior wall of the igloo at all positions and, hence, fully calculate how much of the heat radiated by the human would be transferred through the igloo wall, a model of the convective circulation flow inside the igloo is required. This could also lead to determining whether parts of the igloo wall interior would melt due to the warm air transferring heat to it.

The human inside the igloo was initially assumed to be naked with a body temperature of 306.15K. In more realistic conditions, the human would be wearing clothes, so the body surface temperature would be lower. We assumed a constant human body temperature, but it is likely that the temperature would drop as the body loses heat to the air. We assumed that there would be no heat loss through the ground beneath the igloo, but this would not be the case in reality. Also, there would most likely be other heat sources within the igloo, such as an oil lamp.

Conclusion

Assuming a steady state system of a single human's body heat radiated to the air inside the igloo and then conducted through the igloo wall to the cold exterior, this model predicts that a temperature difference between inside and outside of $\Delta T \approx$ 49K could be maintained.

However, this prediction could be made more accurate by obtaining a model of the convective circulation flow inside the igloo, which is beyond the scope of this paper.

References

[1]http://ecommons.library.cornell.edu/bitstream/1813/125/2/Igloo.pdf
Accessed: 5/2/2011.
[2]http://www.earthgauge.net/wp-content/EG_Snow.pdf
Accessed: 7/2/2011.
[3]P. Tipler, G. Mosca, *Physics for Scientists and Engineers* (4th Ed.), (W.H. Freeman and Company/Worth Publishers 2007), p.646.
[4]http://www.engineeringtoolbox.com/ice-thermal-properties-d_576.html
Accessed: 7/2/2011.
[5]http://hypertextbook.com/facts/2001/AbantyFarzana.shtml
Accessed: 22/2/2011.
[6]http://www.thesnellgroup.com/storage/fck/File/thinkthermally/ThinkThermally_2007_Winter.pdf
Accessed: 7/2/2011.
[7]Wilson, J. Gonz' alex-Espada, et al. *Physics Education* **36 (4)**, 290-292 **(2001)**.
[8]http://www.weatherbase.com/weather/weather.php3?s=20240&refer=&units=metric
Accessed: 7/2/2011.